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Spatial Assessment of Vegetation Condition in a Gas-Flaring Environment Using the Normalized Difference Vegetation Index: Evidence from the Agbada Flow Stations, Rivers State, Nigeria

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ABSTRACT
Gas flaring remains an environmental concern in petroleum-producing regions of the Niger Delta and may impose thermal and atmospheric stresses on surrounding vegetation. This study assessed vegetation condition around the Agbada Flow Stations in Rivers State, Nigeria, using the Normalized Difference Vegetation Index (NDVI) and Geographic Information System (GIS)-based spatial analysis. Landsat satellite imagery obtained from the United States Geological Survey (USGS) Earth Explorer database was pre-processed in ArcGIS and used to derive NDVI from the near-infrared and red spectral bands. The resulting NDVI values were classified and presented as a thematic map, which was examined spatially in relation to four mapped gas-flare locations. NDVI values across the study area ranged from approximately −0.0208 to 0.3620. The spatial distribution was heterogeneous, with relatively lower values occurring in portions of the landscape characterized by built-up surfaces, sparse vegetation and exposed surfaces, while relatively higher values occurred in areas with greater vegetation cover. Some portions of the environment around the mapped flare locations were associated with comparatively lower NDVI values, providing spatial evidence consistent with vegetation stress in the flaring environment. However, the NDVI pattern was not uniform around all flare locations, indicating that land cover, agricultural activity, settlement development and other environmental factors also influence vegetation condition. The study demonstrates the usefulness of Landsat-derived NDVI and GIS for spatial screening and environmental monitoring of vegetation condition around gas-flaring facilities, while emphasizing the need for field verification and multi-temporal analysis for stronger assessment of causality and change over time.
Keywords: Gas flaring; vegetation condition; Normalized Difference Vegetation Index; Landsat; GIS; Agbada Flow Stations; Niger Delta; environmental monitoring.

1. INTRODUCTION

Gas flaring is the controlled combustion of associated natural gas during petroleum exploration and production. It remains an important environmental issue because combustion at flare stacks produces heat and atmospheric emissions while also representing the loss of a potentially useful energy resource. The World Bank's 2026 Global Gas Flaring Tracker reported that global gas flaring reached approximately 167 billion cubic metres (bcm) in 2025, the highest level since 2019 and the third consecutive annual

increase. The continuing scale of flaring reinforces the need for spatially explicit environmental monitoring in petroleum-producing regions.

Vegetation is sensitive to environmental changes because plant growth and productivity depend on temperature, atmospheric conditions, soil properties, water availability and other ecological factors. Gas flaring can modify the local environment through radiant heat and combustion-related emissions, potentially affecting plant physiological performance, vegetation vigour and biomass production. In the Niger Delta, prolonged gas-flaring activity has been associated with vegetation stress and reductions in plant growth and productivity, although responses vary with local environmental conditions (Seiyaboh & Izah, 2017).

The Niger Delta contains a complex mosaic of natural and secondary vegetation, agricultural land, wetlands, settlements, roads and petroleum infrastructure. The Agbada Flow Stations occur within this heterogeneous landscape. The area contains active petroleum-production facilities and surrounding communities and vegetated surfaces at varying distances from flare locations. This spatial complexity is important because vegetation condition around a flare cannot be interpreted from distance alone; land cover, agricultural activity, settlement expansion, exposed soil, drainage and other environmental pressures may also influence remotely sensed vegetation indices.

The Normalized Difference Vegetation Index (NDVI) is widely used to quantify vegetation greenness and spatial variation in vegetation density and condition. It is calculated from the contrasting reflectance of vegetation in the red and near-infrared portions of the electromagnetic spectrum (Rouse et al., 1974; Tucker, 1979). The USGS identifies Landsat-derived NDVI as useful for quantifying vegetation greenness, vegetation density and changes in plant health. NDVI should nevertheless be interpreted as a spectral indicator of vegetation condition rather than as a direct measurement of physiological health.

Remote-sensing investigations elsewhere in the Niger Delta provide useful context for the present study. Floyd and Ruth (2022) reported substantial temporal changes in NDVI around the Oben Gas Flow Station in Edo State, with mean NDVI decreasing from 0.62 in 1987 to 0.18 in 2002 before increasing to 0.26 in 2019. Morakinyo et al. (2023), using Landsat 7 and Landsat 8 imagery across 11 flaring sites in Rivers State, demonstrated that remotely sensed vegetation responses could be used to investigate potentially gas-flaring-related pollution. Morakinyo (2015) similarly reported spatial and temporal changes in vegetation condition around Niger Delta flare sites.

Despite these regional studies, localized evidence for the Agbada Flow Stations remains limited. The present study therefore applies Landsat-derived NDVI and GIS to characterize vegetation condition across the Agbada landscape and examine its spatial relationship with mapped gas-flare locations. The specific objective was to assess vegetation health around the Agbada Flow Stations by determining the spatial distribution and range of NDVI values and evaluating whether areas close to gas-flaring facilities exhibited comparatively reduced vegetation condition.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted around Agbada Flow Stations 1 and 2 in Rivers State, Nigeria, within the Niger Delta region. Agbada is an oil-field landscape containing flow stations, wellheads and associated petroleum infrastructure distributed among rural communities, agricultural areas, wetlands and natural or secondary vegetation. The area falls within Ikwerre Local Government Area and is located approximately 25–40 km northeast of Port Harcourt. The landscape is generally low-lying and includes rivers, creeks, wetlands, settlements, roads and agricultural land.

The Agbada Flow Stations were selected because of their continuing petroleum-production activities and associated gas-flaring facilities, as well as the close occurrence of communities and vegetated areas around the flare locations. These characteristics provide an appropriate setting for spatial assessment of vegetation condition in relation to gas-flaring infrastructure.

2.2 Research Design

The vegetation component employed a cross-sectional spatial assessment based on remote sensing and GIS. Field reconnaissance provided geographic coordinates for mapped flare locations, while Landsat imagery provided spatially continuous information for deriving NDVI. The analysis was designed to characterize vegetation condition across the study landscape and to examine its spatial relationship with gas-flare locations rather than to establish experimental causation.

2.3 Spatial and Satellite Data Acquisition

Geographic coordinates of the Agbada Flow Stations and associated flare stacks were obtained during field reconnaissance using a handheld Global Positioning System (GPS) receiver. The coordinates were imported into the GIS environment and used to map the spatial distribution of the flare locations.

Landsat satellite imagery was acquired for the assessment of vegetation health and land surface temperature within the study area. The imagery was obtained from the United States Geological Survey (USGS) Earth Explorer database. Landsat imagery with suitable spatial resolution and minimal cloud cover was selected and pre-processed before analysis. The datasets were imported into the ArcGIS environment, projected to WGS 1984 UTM Zone 32N, clipped to the study-area boundary and organized for subsequent spatial analysis. The surviving thesis records do not preserve the exact Landsat sensor, acquisition date, scene identifier or original cloud-cover metadata because the computer used for the original processing subsequently failed. These details are therefore not stated in this manuscript rather than being inferred.

2.4 Image Processing and NDVI Derivation

The surviving thesis methodology records indicate that the imagery was pre-processed in ArcGIS, including layer stacking and radiometric correction where required, before NDVI calculation. NDVI was calculated from near-infrared (NIR) and red-band reflectance using the standard expression:

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}$$

The theoretical NDVI range is −1 to +1. Negative or near-zero values may occur over water, built-up or exposed surfaces, while progressively higher positive values generally indicate greater vegetation cover and greenness. The present study therefore interpreted NDVI as a spatial proxy for vegetation condition.

2.5 Spatial Interpretation of NDVI

The resulting NDVI thematic map was examined in relation to the mapped flare locations. Four gas-flare locations were identified across the Agbada study landscape and overlaid on the NDVI distribution to assess the spatial relationship between vegetation condition and the flare locations.

2.6 Analytical Approach

Analysis was descriptive and spatial. The observed NDVI range and the spatial distribution of classified NDVI values were examined in relation to the mapped gas-flare locations and the heterogeneous land-cover characteristics of the study area. The analysis was used to identify areas of relatively lower and higher vegetation condition without assigning a causal effect to gas flaring solely from spatial coincidence.

3. RESULTS

3.1 Spatial Distribution of NDVI

The NDVI map showed substantial spatial variation in vegetation condition across the Agbada Flow Station environment (Figure 1). NDVI values across the study area ranged from approximately −0.0207829 to 0.362008. The mapped values were represented by different shades, with darker tones corresponding to relatively lower NDVI values and lighter tones corresponding to relatively higher NDVI values. Relatively lower NDVI values occurred in several portions of the study area, including areas around built-up surfaces, sparsely vegetated locations and exposed surfaces. Relatively higher NDVI values occurred in portions of the landscape with greater vegetation cover.

The four mapped gas-flare locations were overlaid on the NDVI distribution. The map showed variation in NDVI values around the flare locations, with areas of relatively lower and higher NDVI occurring at different positions within the mapped landscape. The NDVI distribution did not form a uniform pattern around the four flare locations. The values also varied across areas containing settlements, vegetation and other land-cover features, demonstrating a spatially heterogeneous vegetation pattern across the Agbada study area.

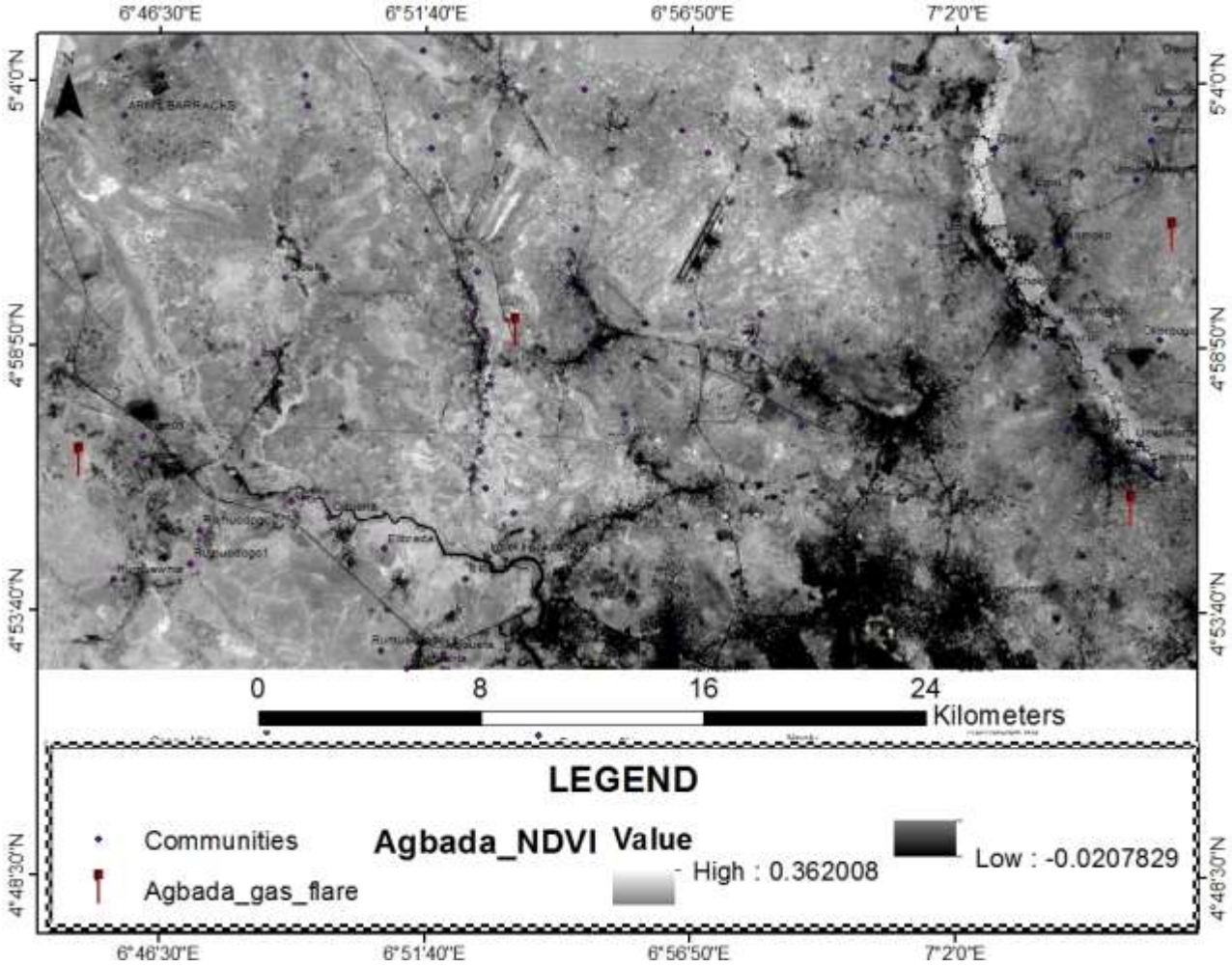

Figure 1. Spatial distribution of NDVI-derived vegetation condition and mapped gas-flare locations around the Agbada Flow Stations.

3.2 Spatial Association with Gas-Flare Locations

Comparison of the NDVI map with the mapped flare locations showed that portions of the flare environment contained comparatively lower NDVI values. However, relatively higher NDVI values were also present at different positions around the mapped flare locations. The observed pattern therefore indicates a spatial association between portions of lower vegetation-index values and the flaring environment, but it does not demonstrate a uniform distance-decay relationship or establish gas flaring as the sole determinant of vegetation condition.

4. DISCUSSION

4.1 Vegetation Condition and the Flaring Environment

The observed NDVI range of −0.0208 to 0.3620 demonstrates substantial spatial variation in vegetation condition across the Agbada landscape. The occurrence of relatively low NDVI around portions of the

flare environment is consistent with the possibility that gas-flaring activity contributes to vegetation stress. Gas flaring produces intense radiant heat and combustion-related emissions that may modify local environmental conditions and affect vegetation physiology. Seiyaboh and Izah (2017) similarly identified elevated temperature, atmospheric pollution and changes in soil conditions among pathways through which gas flaring can affect vegetation in the Niger Delta.

4.2 Consistency with Previous Studies

The Agbada findings are broadly consistent with previous studies of vegetation response around Nigerian flare sites. Floyd and Ruth (2022) documented marked temporal changes in NDVI around the Oben Gas Flow Station, including a decline from 0.62 in 1987 to 0.18 in 2002 followed by partial recovery to 0.26 in 2019. Their results demonstrate that NDVI can reveal substantial changes in vegetation condition in a gas-flaring environment.

Morakinyo et al. (2023) analysed 11 flaring sites in Rivers State using Landsat 7 and Landsat 8 imagery and reported evidence of vegetation responses potentially associated with flaring-related pollution. Morakinyo (2015) also reported lower vegetation-index values in areas close to flare stacks and changes in vegetation condition with distance at Niger Delta flaring sites. The present Agbada assessment extends this regional evidence by providing a localized spatial characterization of NDVI around the Agbada Flow Stations.

4.3 Why the Pattern Is Not Entirely Explained by Distance

The Agbada study area contains settlements, cultivated land, roads, exposed soil, wetlands and patches of natural or secondary vegetation. These land-cover types have different spectral properties and can produce substantial NDVI differences independently of flaring. Agricultural clearing, settlement expansion and other forms of human disturbance may therefore reinforce or obscure the vegetation response attributable to flare emissions.

The results consequently support a nuanced interpretation: the proximity-related increase in NDVI observed in the two sampled corridors is consistent with a flaring-related stress signal, while the broader map demonstrates that the magnitude and distribution of vegetation condition are modified by landscape context. This interpretation avoids attributing every low-NDVI area to gas flaring when some low values clearly correspond to built-up or exposed surfaces.

4.4 Possible Mechanisms of Vegetation Stress

Several mechanisms may contribute to poorer vegetation condition close to flare facilities. Radiant heat can impose thermal stress on nearby vegetation, while combustion-related emissions may alter atmospheric conditions and contribute to deposition of pollutants. Over prolonged periods, these pressures may affect photosynthetic performance, foliar condition and plant growth. Soil-mediated effects may also occur where atmospheric deposition alters soil chemical conditions.

The present NDVI analysis cannot distinguish among these mechanisms because it measured the resulting spectral condition of vegetation rather than individual pollutant concentrations, thermal exposure or soil properties. The findings should therefore be regarded as evidence of spatial vegetation condition compatible with environmental stress in the flaring environment, not as direct measurements of the mechanism responsible.

4.5 Implications for Environmental Monitoring

The results demonstrate the usefulness of Landsat-derived NDVI as a screening indicator for environmental monitoring around petroleum facilities. Remote sensing provides spatially continuous information that can identify locations requiring closer field investigation, especially where relatively low NDVI coincides with persistent flare infrastructure.

For management purposes, NDVI monitoring should ideally be combined with field vegetation surveys, land-use/land-cover information, land-surface temperature, meteorological observations and measurements of relevant soil and atmospheric variables. Such integration would improve the ability to distinguish vegetation stress attributable to gas flaring from changes associated with agriculture, settlement development or other environmental pressures.

The findings also support continued efforts to reduce routine gas flaring through improved gas capture and utilization. Reducing the source of thermal and combustion-related emissions is preferable to relying solely on ecological remediation after environmental stress has occurred.

5. CONCLUSION

This study assessed vegetation condition around the Agbada Flow Stations in Rivers State, Nigeria, using Landsat-derived NDVI and GIS-based spatial analysis. The mapped NDVI values ranged from approximately − 0.0208 to 0.3620, demonstrating substantial spatial variation in vegetation condition across the study landscape.

Relatively lower NDVI values occurred in portions of the landscape surrounding the flaring environment, while relatively higher values occurred in areas with greater vegetation cover. The broader NDVI map was heterogeneous and did not show a uniform pattern around all four mapped flare locations. This pattern is consistent with the possibility of vegetation stress associated with the flaring environment, while also demonstrating the influence of land cover, agricultural activity, settlement development and other environmental factors.

The study therefore concludes that gas flaring represents an important potential environmental stressor within the Agbada landscape, but the available NDVI evidence does not justify attributing all observed vegetation differences to flaring alone. Landsat-derived NDVI and GIS provide useful tools for environmental monitoring, while future assessments should incorporate multi-temporal imagery, quantitative spatial analysis and field-based vegetation measurements to strengthen causal attribution and quantify changes in vegetation condition over time.

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